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External Ionizing Radiation Exposure During Cargo/Vehicle Radiographic Inspection of Nigerian Ports Authority, Onne, Rivers State, Nigeria

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Abstract

Cargo inspection technology encompasses the use of ionizing radiation to examine materials, cargo and conveyances at various ports of entry crossing for security related items. Exposure of humans to these ionizing radiation may lead to health hazards therefore evaluation of external ionizing radiation exposure during the normal scanning operation and when the scanner is not in operation at the Nigeria Ports Authority, Onne seaport, Rivers State was carried out in order to estimate the health hazards and risks associated with such exposure. An in-situ measurement of the background radiation of the surrounding environment of the scanning center was carried out using two well calibrated nuclear radiation meter (Digilert-50 and Radalart-100) and a Global Positioning System (GPS). The area was divided into four (4) zones and radiation exposure rate taken during cargo scanning and also when it is not scanning. The mean radiation exposure rate of four locations during scanning operation ranges from 0.018±0.001mRhr^{-1} to 0.060±0.0039mRhr^{-1} and the equivalent dose rate ranges from 1.514±0.08mSvy^{-1} to 5.004±0.33mSvy^{-1}. The mean exposure rate of the four locations when the scanning facility was not working ranges from 0.015±0.0024mRhr^{-1} to 0.018±0.001mRhr^{-1} while the equivalent dose rate ranges from 1.29±0.09mSvy^{-1} to 1.49± 0.09mSvy^{-1}. The average exposure rate and equivalent radiation dose obtained for each location of the study area including office blocks are above the recommended safe value of 0.013mRhr^{-1} and 1.0mSvy^{-1} respectively. The results obtained show that the background ionizing radiation of the area has been impacted due to Cargo scanning operation.

Keywords: Radiography, Radiation, Equivalent dose, Exposure, Digilert , Onne and Cargo

1. Introduction

The current insecurity in Nigeria due to insurgence, terrorist attack, kidnapping and proliferation of arms and other weapons lead to the establishment of facility screening technology that uses x-rays and gamma rays to detect objects inside a cargo and personal baggage's in all the sea ports and borders within the country. Cargo inspection using gamma rays imaging technology provides clear radiographic images of a container showing the outlines and the density of the content (Orphan *et al.*, 2001). This technology also encompasses the use of ionizing radiation to examine materials, cargo and conveyances at various ports of entry crossing for security related items (Bennett and Chin, 2008).

Background ionizing radiation is the radiation of man's natural environment, consisting of what comes from cosmic rays, the naturally radioactive elements of the earth and from within men body (Ballinger, 1991). Apart from the naturally occurring radiation in the atmosphere and terrestrial deposits, human activities have gradually led to the increase of background ionizing radiation. In Nigeria, outdoor background ionizing radiation profile has received much attention than indoor background ionizing radiation, even though studies have established the presence of dangerous background ionizing radiation within buildings (Jwanbot et al., 2012), because of this introduction of cargo and baggage screening technology that disperses radiation to the environment unintentionally.

Khan *et al.*,(2004) carried a research on Radiation dose equivalent to stowaways in vehicle, radiation dose equivalent from the sources were measured using different modalities with phantom placed in four positions inside the truck on a cargo container, the maximum dose equivalent of 50nSv(5µrem) from a single scan in gamma ray imaging was obtained and also the result obtained when measurement was taken for CXR-600 container scanning ranges from 0.0172mSv to 0.0220mSv per scan and all these does not pose immediate health hazard to an individual exposed. ILO, (2011) carried out study on scan for security and screening for theft and contraband, reported mean dose of cargo scanner of (0.2- 0.4) µSv per scan which is slightly higher than 0.1µSv dose equivalent recommended by NCRP.

IMRH, (2012) carried out a scientific study on external ionizing radiation exposure during cargo /vehicle Radiographic inspection, the result of the field study show that there are no occupational and safety hazards for drivers if the scanning of the trucks/vehicle was performed using LINAC high energy x-ray scanning technology since the drivers will not be inside the truck. But the background ionizing radiation of the area might increase due to scattered radiations during scanning and this may lead to unnecessary exposure of the general public.

External exposure is the main route in industrial radiography. High doses are produces in radiography such that occupational workers exposed to the beam or in close contact with an unshielded source might receive a dose that results in radiation injuries. Poor handling procedures such as inadequate engineering control of equipment (Linac) , safety culture, and management and the inadequate assessment and monitoring of potential doses are the cause for most of the reported cases of overexposure to external radiation in industrial radiography. (Kamara and Dunn, 2014). Exposure rate more than 1.0msvy^{-1} will lead to radiation induced sickness like cancer, cataract, atrophy of the kidney and so on (Ononugbo et al., 2011) and so the need to assess exposure rate of the general public to ionizing radiation within the scanning environment which is the basis for this work. This result of this work will serve as baseline data for future work.

2. Materials and Method

The study area is located at the Federal Ocean terminal (FOT) section of the Onne sea port complex within the West African Container Terminals (WACTS). The geographical location spans between latitude N04^0 40' and longitude E007^0 09', and it cuts across NOTORE jetty and Bonny Island. There are two major terminals at Onne port namely Federal Ocean Terminals (FOT) and Federal Lighters Terminals (FLT) as shown in Figure 1.

The area was divided into (4) four zones, (6) six readings were taken for each zone at different points when the scanning is ON and when it is OFF, making a total of (12) twelve readings for each zone and a total of 48(forty eight) for all the four zones. An in-situ background radiation measurement was adopted, at each point (5) five readings were taking randomly using hand held digital nuclear radiation monitor Radalert-100 and Digilert-50 simultaneously and an average of the (5) five readings were taken. The nuclear radiation monitor is a health and safety instrument that measures alpha, beta, gamma and x-ray radiation(Avwiri *et al.*, 2012).The Global Positioning System (GPS) is used to measure the location prior to taking each measurement in the field.

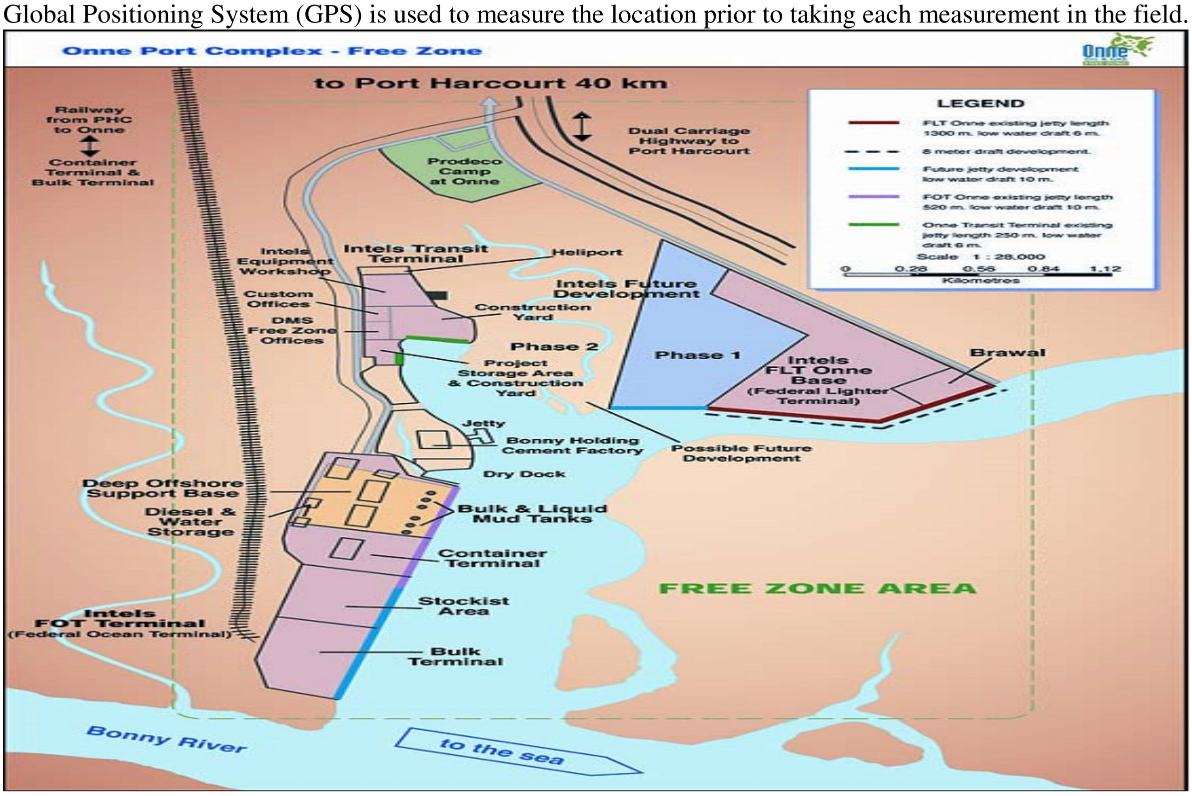

Fig. 1: Map of the Study Area

The readings were taking between hours of 1100hr to 1500hr. The tube of the radiation meter was raised to a standard height of 1.0m above the ground level with its window facing the scanning source and then vertically downward (Ononugbo *et al.*, 2011). The Gieger muller tube generates a pulse current each time radiation passes through the tube and causes ionization (Avwiri *et al.*, 2012). Each pulse is electronically detected and registered as a count. The radiation meter was characterized to read in milli-Roetgen per hour and was converted to milli-Sievert per year using the relation

$$1\text{mRh}^{-1} = \left(\frac{0.96x24x365}{100}\right) mSv/y \qquad (1)$$

3. Results

The radiation exposure rate measured within the Cargo scanning area of Nigerian Ports Authority when the equipment is ON and OFF are shown in the Tables 1- 4. Measurement was done when the

Table1: Radiation level at the Exit to the scanning centre

S/N	Sample Location	Geographical Cordinates	Radalert-50	Digilert-100	Radiation Level(Off) (mR/hr)	Equivalent Dose(Off) (mSv/yr)	Radalert-50	Digilert-100	Radiation Level(On) (mR/hr)	Equivalent Dose(On) (mSv/yr)
1.	Exit Area1	N04^{0} 40’ 28.32” E007^{0} 09’ 05.3”	0.019	0.021	0.021±0.0016	1.766±0.135	0.055	0.063	0.059±0.0034	4.962±0.286
2.	Exit Area2	N04^{0} 40’ 29.0” E007^{0} 09’ 04.9”	0.020	0.024	0.022±0.0004	1.850±0.034	0.060	0.070	0.065±0.0034	5.466±0.286
3.	Exit Gate	N04^{0} 40’ 28.8” E007^{0} 09’ 04.8”	0.011	0.021	0.016±0.0009	1.346±0.076	0.058	0.064	0.062±0.0033	5.214±0.278
4.	Exit Area3	N04^{0} 40’ 28.5” E007^{0} 09’ 05.8”	0.012	0.018	0.015±0.0007	1.261±0.059	0.060	0.062	0.061±0.0035	5.130±0.294
5.	Exit Area4	N04^{0} 40’ 28.2” E007^{0} 09’ 05.0”	0.015	0.013	0.014±0.0007	1.177±0.059	0.054	0.062	0.058±0.0045	4.878±0.378
6.	Exit Area5	N04^{0} 40’ 28.0” E007^{0} 09’ 04.9”	0.011	0.015	0.013±0.0007	1.093±0.059	0.055	0.063	0.058±0.0053	4.373±0.446
		Mean			**0.017±0.0008**	**1.416±0.070**			**0.060±0.0039**	**5.004±0.328**

Table 2: Radiation level at the Entrance to the scanning centre

S/N	Sample Location	Geographical Coordinates’	Radalert-50	Digilert-100	Radiation Level(Off) (mR/hr)	Equivalent Dose(Off) (mSv/yr)	Radalert-50	Digilert-100	Radiation Level(On) (mR/hr)	Equivalent Dose(On) (mSv/yr)
1.	Entrance1	N04^{0} 40’ 27.3” E007^{0} 09’ 04.3”	0.018	0.022	0.020±0.0014	1.782±0.118	0.046	0.054	0.050±0.0033	4.205±0.276
2.	Entrance2	N04^{0} 40’ 27.0” E007^{0} 09’ 03.7”	0.019	0.017	0.018±0.0012	1.514±0.101	0.040	0.056	0.048±0.0023	4.037±0.193
3.	Gen.room	N04^{0} 40’ 26.8” E007^{0} 09’ 04.8”	0.016	0.020	0.018±0.0012	1.514±0.101	0.041	0.051	0.046±0.0025	3.868±0.210
4.	Entrance3	N04^{0} 40’ 28.0” E007^{0} 09’ 03.7”	0.014	0.020	0.017±0.0009	1.430±0.016	0.054	0.058	0.056±0.0040	4.709±0.336
5.	Entrance4	N04^{0} 40’ 29.0” E007^{0} 09’ 03.7”	0.018	0.016	0.017±0.0015	1.430±0.126	0.048	0.056	0.052±0.0040	4.373±0.336
6.	Entrance5	N04^{0} 40’ 27.8” E007^{0} 09’ 03.5”	0.013	0.019	0.016±0.0012	1.430±0.126	0.050	0.054	0.052±0.0043	4.541±0.362
		Mean			**0.018±0.0012**	**1.486±0.094**			**0.051±0.0034**	**4.289±0.291**

Table 3: Radiation level at the Office Block of the scanning centre

S/N	Sample Location	Geographical Coordinates	Radalert-50	Digilert-100	Radiation Level(Off) (mR/hr)	Equivalent Dose(Off) (mSv/yr)	Radalert-50	Digilert-100	Radiation Level(On) (mR/hr)	Equivalent Dose(On) (mSv/yr)
1.	CP Office	N04^{0} 40’ 27.5” E007^{0} 09’ 04.4”	0.014	0.016	0.015±0.0015	1.261±0.126	0.019	0.017	0.018±0.0009	1.514±0.076
2.	Block1	N04^{0} 40’ 27.7” E007^{0} 09’ 04.9”	0.012	0.016	0.014±0.0004	1.177±0.059	0.015	0.019	0.017±0.0009	1.430±0.076
3.	Block2	N04^{0} 40’ 27.9” E007^{0} 09’ 04.9”	0.015	0.019	0.017±0.0019	1.430±0.084	0.016	0.020	0.018±0.0005	1.514±0.042
4.	Block3	N04^{0} 40’ 28.0” E007^{0} 09’ 05.8”	0.016	0.014	0.015±0.0014	1.261±0.118	0.016	0.018	0.017±0.0009	1.430±0.076
5.	Block4	N04^{0} 40’ 28.3” E007^{0} 09’ 05.2”	0.015	0.019	0.017±0.0009	1.430±0.059	0.017	0.024	0.021±0.0012	1.766±0.101
6.	Block5	N04^{0} 40’ 28.6” E007^{0} 09’ 05.5”	0.010	0.018	0.014±0.0010	1.177±0.084	0.015	0.019	0.017±0.0010	1.430±0.084
		Mean			**0.015±0.0024**	**1.289±0.088**			**0.018±0.0009**	**1.514±0.076**

Table 4: Radiation level at the Adjacent to the scanning centre

S/N	Sample Location	Geographical Coordinates’	Radalert-50	Digilert-100	Radiation Level (Off) (mR/hr)	Equivalent Dose (Off) (mSv/yr)	Radalert-50	Digilert-100	Radiation Level (On) (mR/hr)	Equivalent Dose (On) (mSv/yr)
1.	Adj. Scan1	N04^{0} 40’ 26.2” E007^{0} 09’ 04.8”	0.014	0.018	0.016±0.0012	1.346±0.101	0.059	0.071	0.065±0.0034	5.466±0.286
2.	Adj. Scan2	N04^{0} 40’ 26.8” E007^{0} 09’ 05.1”	0.016	0.019	0.017±0.0021	1.430±0.177	0.050	0.064	0.057±0.0033	4.793±0.276
3.	Adj.Scan3	N04^{0} 40’ 26.7” E007^{0} 09’ 05.2”	0.021	0.015	0.018±0.0007	1.514±0.059	0.038	0.048	0.043±0.0026	3.616±0.219
4.	Adj. Scan4	N04^{0} 40’ 26.4” E007^{0} 09’ 25.9”	0.014	0.020	0.017±0.0014	1.430±0.118	0.035	0.047	0.041±0.0025	3.448±0.210
5.	Adj. Scan5	N04^{0} 40’ 28.0” E007^{0} 09’ 04.7”	0.019	0.017	0.018±0.0009	1.514±0.076	0.058	0.064	0.061±0.0025	5.130±0.210
6.	Adj.Scan6	N04^{0} 40’ 28.5” E007^{0} 09’ 04.9”	0.017	0.013	0.015±0.0005	1.261±0.042	0.040	0.046	0.043±0.0022	3.616±0.185
		Mean			**0.017±0.0011**	**1.416±0.096**			**0.044±0.0028**	**4.345±0.231**

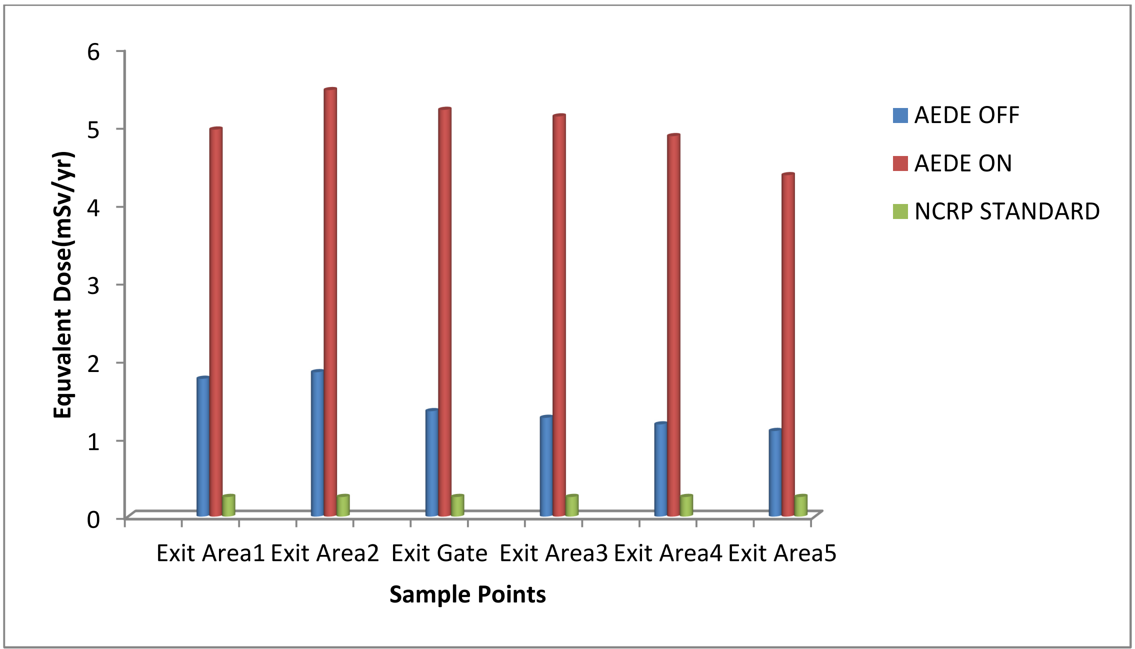

Fig.1: Comparison of Equivalent dose within Exit Area during ON and OFF with NCRP standard dose limit.

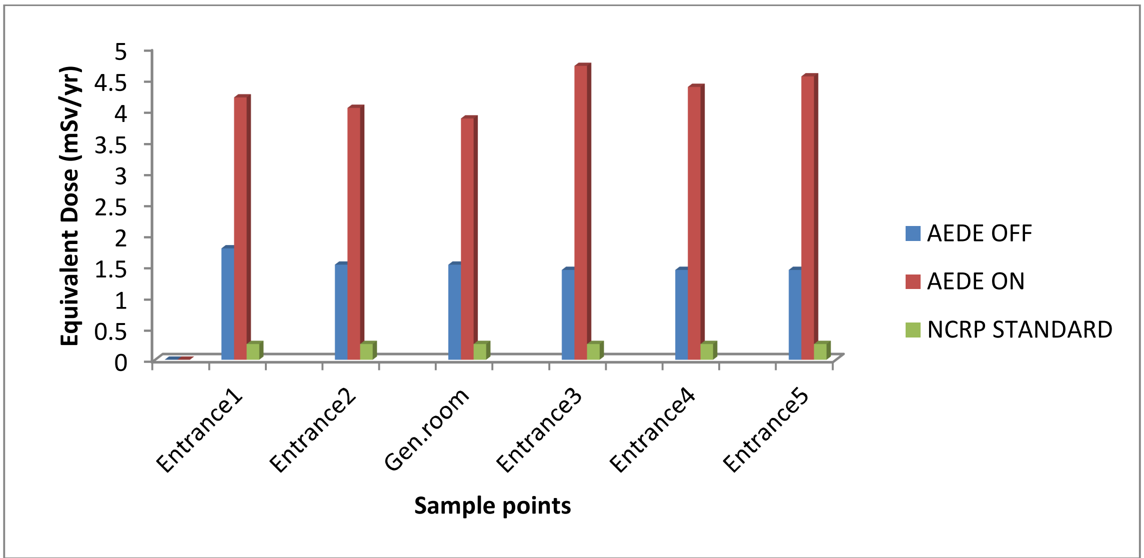

Fig. 2: Comparison of Equivalent dose within the Entrance Area during ON and OFF with NCRP standard dose limit.

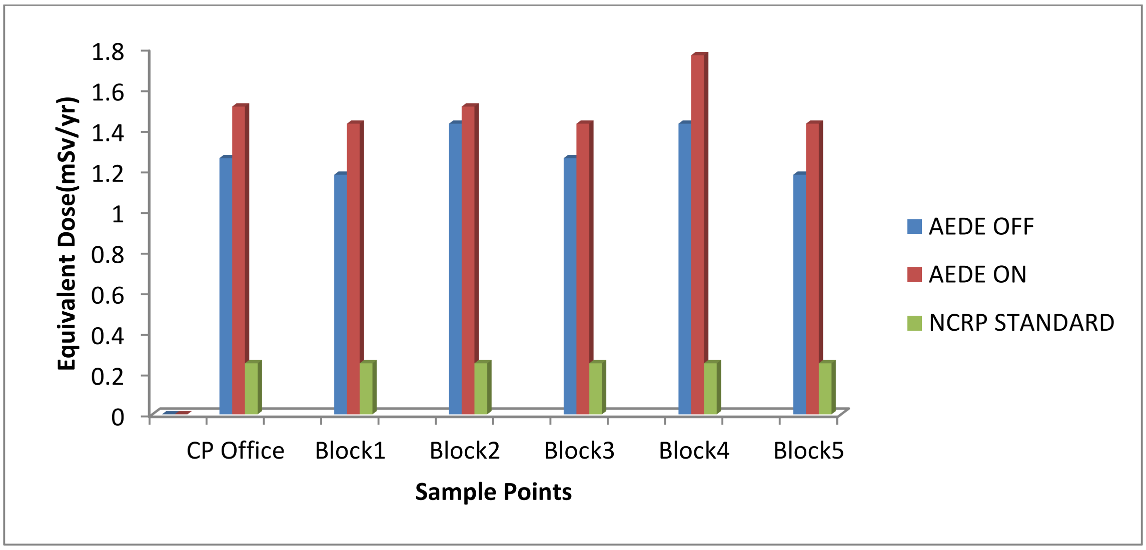

Figure 3: Comparison of Equivalent dose within the Office block during ON and OFF with NCRP standard dose limit

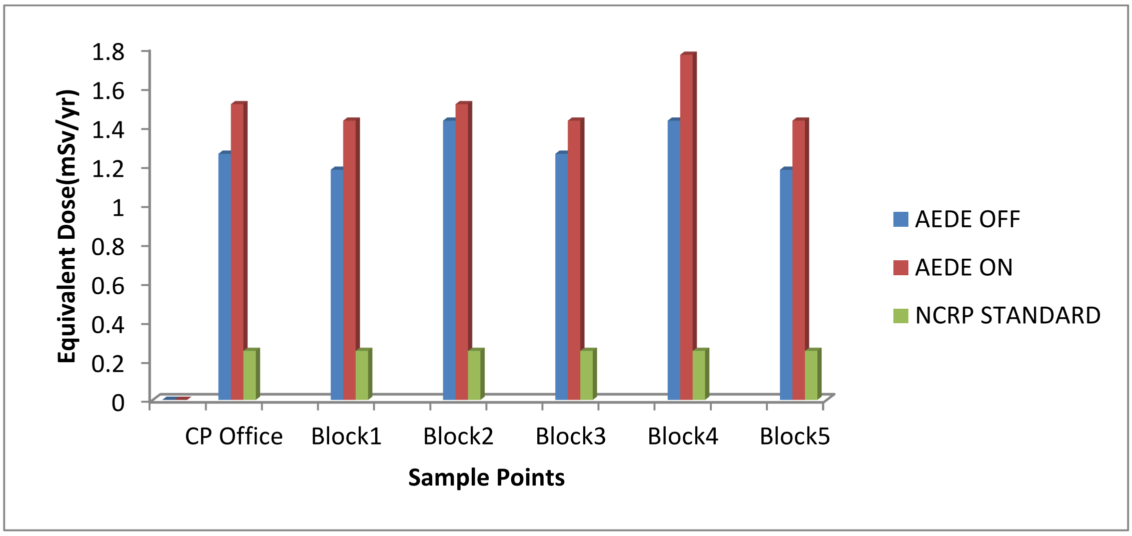

Fig.4: Comparison of Equivalent dose within the Adjacent Scanning Area during ON and OFF with NCRP standard dose limit.

when the radiographic unit was scanning and also when it is off. The exposure rate at the exit to the scanning centre ranges from 0.013mRhr^{-1} to 0.022 mRhr^{-1} when the equipment is OFF and 0.052mR/hr to 0.065mR/hr during the scanning operation as shown in Table 1. The radiation dose equivalent calculated ranges from 1.093±0.059 to 1.850±0.034mSvy^{-1} when the equipment was not working (OFF) and 4.373±0.45 to 5.466±0.29mSvy^{-1} during scanning operation.

Table 2 show the radiation exposure level of sampled points along the Entrance to the cargo scanning centre which ranges from 0.017mR/hr to 0.020mR/hr when the equipment is not scanning (OFF), and 0.046mR/hr to 0.056mR/hr when the equipment is scanning (ON).The generator room recorded the least radiation exposure, while the Entrance 3 has the highest level of exposure which may be as result of backscatter radiation from the equipment since both the exit and entrance are not shielded to allow container truck to drive in and out of the scanning compartment. The equivalent dose calculated ranged from 1.430±0.126 to 1.514±0.101mSvy^{-1} when it is not scanning while during scanning the equivalent dose ranges from 3.868±0.210 to 4.709±0.336 mSvy^{-1}.

Table 3 show the radiation exposure at the office blocks of the scanning centre. The office block recorded mean radiation level of 0.014mR/hr to 0.017mR/hr when the equipment is not scanning (OFF), while the mean radiation of 0.017mR/hr to 0.021mR/hr was recorded when the equipment was scanning (ON). Though the equivalent dose of radiation calculated which ranged from 1.177±0.101 to 1.2610±0.026 mSvy^{-1} and 1.430 to

1.766±0.101mSvy^{-1} when the machine was not scanning and during scanning respectively, are still higher than the recommended safe limit of 1.0mSvy^{-1} for residential and office buildings.

Table 4 shows the radiation level around the Adjacent of the scanning facility that is an open place around the scanning area. This area recorded an exposure rate of 0.015mR/hr to 0.018mR/hr when the equipment is not scanning (OFF) and 0.041mR/hr to 0.065mR/hr during scanning operation (ON). Adjacent Scanning Area 6 recorded the least and Adjacent Scanning Area 3 and 5 has the highest when the equipment is not scanning (OFF). Adjacent area 1 recorded the highest level of radiation during scanning, while adjacent area 4 has the least because of its distance from the scanning center. The equivalent doses calculated ranges from 1.261±0.042 to 1.514±0.065mSvy^{-1} and 3.448±0.210 to 5.466±0.286 mSvy^{-1} when the machine is not scanning and when it is scanning respectively. Figures 1- 4 are the comparison of the equivalent dose rates measured when the scanner is not in operation and when it is operating with the minimum safe limit for radiological workers recommended by NCRP.

4. Discussion

The result of in-situ measurement of the environment of radiographic inspection area of Nigerian's Ports authority as presented above shows that high doses of radiation are emitted during the scanning operations. The highest equivalent dose rate of 5.05 mSvy^{-1} recorded at the exit area shows that there are scattered radiations from the scanner unit during operation which has affected the background radiation level of the area. It was also observed that when the scanner was not working, higher exposure rate was also measured at this exit area. The office blocks have the least value of 0.018mR/hr which corresponds to equivalent absorbed dose of 1.514mSv/yr during the normal inspection operation. Despite the shielding of the office blocks with lead coated doors and windows and also that building is not within the exclusive zone, it still recorded high dose of radiation which implies that office workers in that building might be exposed to high dose of ionizing radiation. The Exit gate Area is always open to allow free movement of the cargo/ truck within the scanning facility, and are within the exclusive zone in which radiation exposure level is believed to be high and the researcher observed workers walking around this area without any form of personnel protective coats nor personnel dosimeter to monitor their absorbed dose of radiation during their working hours.

Adjacent area which is directly opposite the exclusive zone but slightly far from the scanning area also recorded high dose of radiation during scanning operation and even when the scanner was off. According to Kamara and Dunn (2014), any exposure to ionizing radiation has the tendency to change the biological make up of the human body which may result in radiation induced sicknesses. The international Basic Safety Standard (BSS) for the protection against ionizing radiation specify the basic requirements for the protection of people against exposure to ionizing radiation and for the safety of the radiation sources. The implementation of those requirements will help to reduce unnecessary exposure and reduce doses absorbed as low as reasonably achievable.

The result of this study show that the entire area (non exclusive and exclusive zone) recorded high doses of radiation which could be as a result of poor handling procedures such as inadequate engineering control of Linac (radiographic unit) used for the cargo scanning, safety culture and management and the inadequate assessment and monitoring of potential doses required for the scanning operation. Only the exclusive zone is expected to have high radiation dose but even the surrounding environment has been impacted showing engineering error or unqualified personnel handling the machine.

The results obtained are higher than that obtained by ACS (2014), which recorded an equivalent dose of 2μSv per scan (0.73mSv/yr) is received by people in those surroundings during an X-ray scanning of a container, this value is really small compare to 5.05mSv/yr that was obtained in this work. This discrepancy may be as a result different engineering controls and safety management of the scanners. Figures 1 to 4 are comparison of equivalent dose rates measured with ICRP (2012) dose limit for members of the public. Equivalent dose rates of all the four areas surveyed exceeded the safe limit of 1.0mSvy^{-1} recommended for the general public. This may be due to scattered radiation from the cargo / vehicle scanning center which may be due to non- compliance with safety procedures (IMRH, 2012, ICRP, 2012). The mean equivalent dose during scanning is far below 20mSv/yr for radiological workers recommended by International Commission on Radiological Protection (ICRP, 1993), though about 97.9% of the sampled area exceeded the acceptable background radiation by ICRP when the equipment is not scanning. The overall result show that the area have been radiologically polluted, though it may not have immediate health implication but long time exposure could lead to radiation induced health hazard such as erythema, skin cancer, genetic mutation and sterility (Avwiri, 2011).

Conclusion

The terrestrial radioactivity survey of Nigerian Ports Authority Cargo Screening Centre, Onne, Rivers State has been carried out. The profile shows that the background radiation level have been impacted by the operation of

Cargo Scanning machine in that vicinity and other industrial activities going on the site. The radiation level within the scanning environment is far above the background radiation of 0.013mR/hr, while dose equivalent obtained exceed that of radiation limit of 1.0msV/yr for general public recommended by UNSCEAR (2003).The result during scanning also shows that is within the dose limit for an individuals within the cargo container during scanning recommended by NCRP (2003). However, the results indicate the need for immediate monitoring of the staff of the screening center since their offices recorded high radiation doses. Stowaways and members of the public around the scanning center may at long run be exposed to a lethal dose of radiation if proper engineering control of the scanner is not implemented since the whole environment recorded high dose of radiation. The background ionizing radiation of the study area has been impacted by the radiation cargo scanning operation. Therefore the researcher recommends that:

- The staff and operators of this equipment should be given regular radiation safety training and retraining.
- Regular and periodic monitoring of radiation dose levels absorbed by the staff and operators of those scanning facilities through the use of personal dosimeters.
- Proper maintenance of the scanning facility to avoid/reduce unnecessary scattered radiation in order to reduce the radiological burden of the environment.
- Offices for the staff should be shifted at a reasonable distance away from the exclusive area of the scanning center.

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